AD-A173 008 AN EXTENSION OF THE SPLIT WINDOW TECHNIQUE FOR THE RETRIEVAL OF PRECIPITABLE WATER(U) AIR FORCE GEOPHYSICS LAB HANSCOM AFB MA T J KLEESPIES ET AL. 03 OCT 86 1/1

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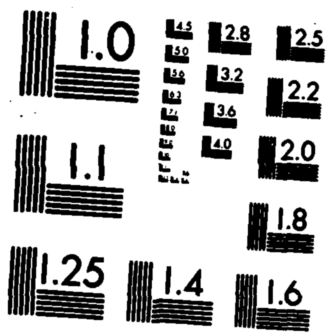

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AD-A173 008

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution Unlimited
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) AFGL-TR-86-0201	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Air Force Geophysics Laboratory — 6b. OFFICE SYMBOL (If applicable) LYS	7a. NAME OF MONITORING ORGANIZATION
6c. ADDRESS (City, State, and ZIP Code) Hanscom AFB Massachusetts 01731	7b. ADDRESS (City, State, and ZIP Code)
8a. NAME OF FUNDING/SPONSORING ORGANIZATION — 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 62101F; PROJECT NO. 6670; TASK NO. 17; WORK UNIT ACCESSION NO. 06

DTIC ELECTE OCT 1 4 1986 S D A

11. TITLE (Include Security Classification)
An Extension of the Split Window Technique for the Retrieval of Precipitable Water

12. PERSONAL AUTHOR(S)
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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Reprint	FROM ____ TO ____	1986 October 3	4

16. SUPPLEMENTARY NOTATION *NOAA/NESDIS, Washington DC - Reprinted from American Meteorological Society Second Conference on Satellite Meteorology/Remote Sensing and Applications May 13-16, 1986 Williamsburg, VA.

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Remote sensing, Precipitable water, Satellite meteorology

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The split window technique has been demonstrated to be a viable method of removing effects of atmospheric attenuation in order to make a more accurate estimate of surface properties. This technique has also been used to estimate low level water vapor fields. In this paper we make an extension to the split window technique such that it is possible to estimate total precipitable water.

The essence of the split window technique is making observations of the earth in two differentially absorbing windows. We extend this technique by making observations in the split window under conditions where the atmospheric contribution to the upwelling radiance is essentially invariant, but the surface contribution changes markedly. Under these conditions it is possible to write a set of simultaneous equations and solve them for the transmittance of the split window, and from that deduce the quantity of the primary absorber, water.

The conditions under which this extension is valid basically fall under two catagories; that of variation in time, and that of variation in space. Consecutive observations of a land surface from a geosynchronous satellite during the heating cycle of the day would be (cont'd)

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT	21. ABSTRACT SECURITY CLASSIFICATION
☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	UNCLASSIFIED

22a. NAME OF RESPONSIBLE INDIVIDUAL	22b. TELEPHONE (Include Area Code)	22c. OFFICE SYMBOL
Thomas J. Kleespies	617-377-3136	AFGL/LYS

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

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One example. Another would be observations from either a geosynchronous or polar orbiting satellite of immediately adjacent land and water surfaces with contrasting skin temperatures.

This paper will present the theoretical considerations of this extension to the split window technique, as well as applications of the AVHRR instrument. Keywords: Remote Sensing

1.13 AFGL-TR-86-0207

Accession For
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Justification

By
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AN EXTENSION OF THE SPLIT WINDOW TECHNIQUE FOR THE RETRIEVAL OF PRECIPITABLE WATER

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1. INTRODUCTION

The split window takes its name from the fact that not one but two measurements are made in the atmospheric window region near 11 micrometers. The two channels are situated such that they "see" the same absorbers, but in differing amounts. The intent of split window observations is to correct for the effects of atmospheric attenuation, and arrive at a better estimate of surface temperature than can be achieved from a single channel observation. McMillin and Crosby (1984) present a detailed discussion of the split window technique and a review of the literature.

In this paper we extend the concept of the split window to deduce the atmospheric attenuation, and since the primary absorber near 11 micrometers is water vapor, we can estimate precipitable water.

2. MATHEMATICAL DERIVATION

The upwelling longwave infrared radiance from a plane parallel, non scattering atmosphere in local thermodynamic equilibrium can be written as

$$I = B_s\tau_s + \int_{\tau_s}^{1} B d\tau \qquad 1)$$

where I is the radiance measured by the satellite, B is the Planck radiance, τ is transmittance from a given level to the top of the atmosphere, the subscript s refers to the surface of the earth, and the integral is the radiance originating from the atmosphere alone. Equation 1 may also be written as

$$I = B_s\tau_s + \bar{B}_a(1-\tau_s) \qquad 2)$$

where $\bar{B}_a$ is a weighted average given by

$$\bar{B}_a = \frac{\int_{\tau_s}^{1} B d\tau}{\int_{\tau_s}^{1} d\tau} \qquad 3)$$

Consider observations of the earth under conditions where the surface contribution to the outgoing infrared radiance varies markedly, but where the atmospheric contribution changes very little. We can now write a set of four equations, one for each of the two channels, and one for each of the different surface observing conditions:

$$I^1_{11} = B^1_{s_{11}}\tau_{s_{11}} + \bar{B}_{a_{11}}(1 - \tau_{s_{11}}) \qquad 4a)$$

$$I^1_{12} = B^1_{s_{12}}\tau_{s_{12}} + \bar{B}_{a_{12}}(1 - \tau_{s_{12}}) \qquad 4b)$$

$$I^2_{11} = B^2_{s_{11}}\tau_{s_{11}} + \bar{B}_{a_{11}}(1 - \tau_{s_{11}}) \qquad 4c)$$

$$I^2_{12} = B^2_{s_{12}}\tau_{s_{12}} + \bar{B}_{a_{12}}(1 - \tau_{s_{12}}) \qquad 4d)$$

where the superscripts 1 and 2 refer to the viewing conditions and the subscripts 11 and 12 refer to the nominal 11 and 12 micrometer channels in the split window. We can eliminate the atmospheric term $\bar{B}a$ by differencing to yield two equations

$$\Delta I_{11} = \Delta B_{s_{11}}\tau_{11} \qquad 5a)$$

$$\Delta I_{12} = \Delta B_{s_{12}}\tau_{12} \qquad 5b)$$

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where

$$\Delta I_{11} = I^1_{11} - I^2_{12} \quad 6a)$$

$$\Delta B_{11} = B^1_{11} - B^2_{12} \quad 6b)$$

and similarily for ΔI_{12} and ΔB_{12}.

The ratio of transmittances in the two channels may be formed by dividing equations 5) to yield

$$\frac{\tau_{11}}{\tau_{12}} = \frac{\Delta I_{11}\ \Delta B_{s_{12}}}{\Delta I_{12}\ \Delta B_{s_{11}}} \quad 7)$$

Following the approach of McMillin (1971), equation 7) can be linearized by converting from radiances to temperatures, the ΔB_s become ΔT_s and cancel, and we are left with

$$\frac{\tau_{11}}{\tau_{12}} = \frac{\Delta T_{11}}{\Delta T_{12}} \quad 8)$$

To review, we have derived an expression for the ratio of transmissivities in the split window near 11 micrometers. Inherent in the derivation are multiple observations of the earth through the split window under conditions where the surface contribution to the upwelling radiance changes markedly, but the atmospheric contribution is essentially invariant. The resulting ratio of transmittances is then shown to be merely the ratio of the differences in brightness temperatures observed under the two conditions. This ratio can be shown to be related to precipitable water (see Chesters et al., 1983).

3. SIMULATION OF TECHNIQUE

In order to test this technique, radiances were computed simulating data from the Advanced Very High Resolution Radiometer (AVHRR) using techniques described by Weinreb and Hill (1980). Temperature and moisture profiles were taken from 304 radiosondes in North America for three consecutive synoptic times beginning at 12Z, 8 June 1982. Since all reporting radiosondes were used, a wide diversity of airmasses were available, from tropical to arctic, and from a range of surface elevations. Local zenith angles were randomly assigned to the radiosondes in order to simulate the distribution of local zenith angles encountered during satellite overpasses of the radiosonde network.

The brightness temperatures were perturbed with normally distributed random noise with a mean of zero and standard deviation of .12 degrees Kelvin, in order to emulate the instrumental error. The surface skin temperature was taken to be the surface air temperature, then incremented 10 degrees for the T's in equation 8. The comparison between the estimated and actual transmissivity ratios are given in Figure 1. The relative lack of scatter is indicative that the assumptions used in the derivation of equation 8) are valid, at least in a theoretical sense.

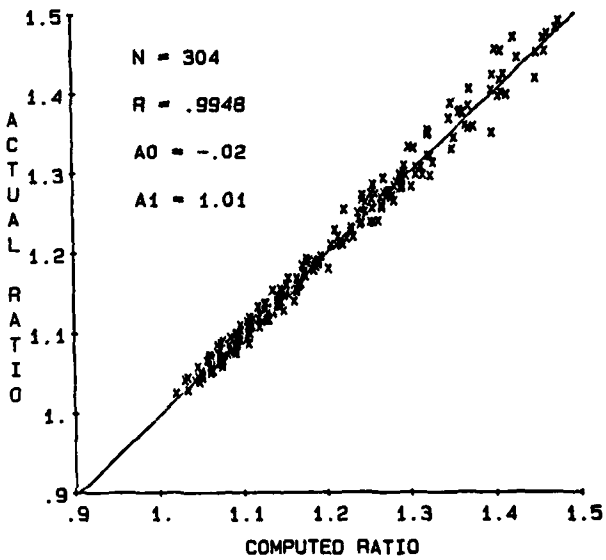

Figure 1. Comparison between actual transmittance ratio and transmittance ratio computed from equation 8.

Next it is desirable to be able to relate this transmissivity ratio to an atmospheric parameter. Since the transmissivities are from the surface to the top of the atmosphere, and the primary absorber is water vapor, it follows that we should try to relate the transmissivity ratio to total water in the column. Simple linear regression between the transmissivity ratio and precipitable water was performed as a first attempt. The choice of a linear relationship is justified by the scatter diagram of actual transmission ratio versus precipitable water in Figure 2. The radiosonde precipitable water was adjusted by the secant of the zenith angle to make it correspond with the slant path of the transmissivities. The regression coefficients were derived from the radiosondes mentioned above, and tested on an independent set of 308 radiosondes in North America for three consecutive synoptic times beginning on 12Z, 10 June 1982. Transmissivity ratios were computed from the independent set of radiosondes using a 10 degree Kelvin surface temperature difference and a NEDT of .12 degrees Kelvin. Again random zenith angles were assigned to the

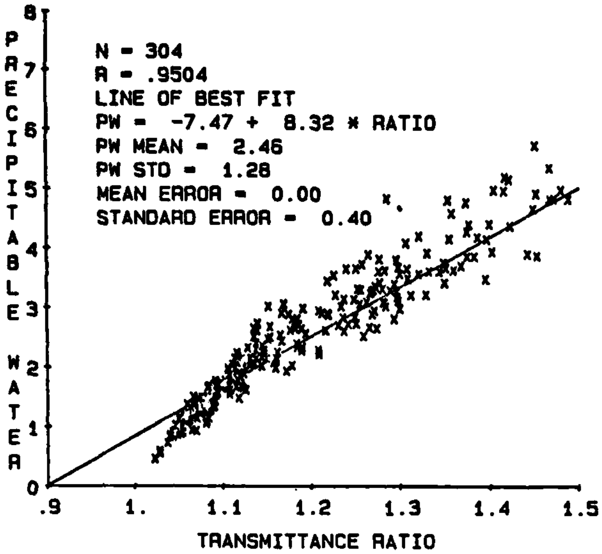

Figure 2. Actual transmittance ratio versus precipitable water.

radiosondes. The precipitable water was computed from this transmissivity ratio with the regression coefficients determined from the dependent set. The comparison with the estimated and observed precipitable water is shown in Figure 3. As can be seen the results are quite good, with an explained variance of .903 .

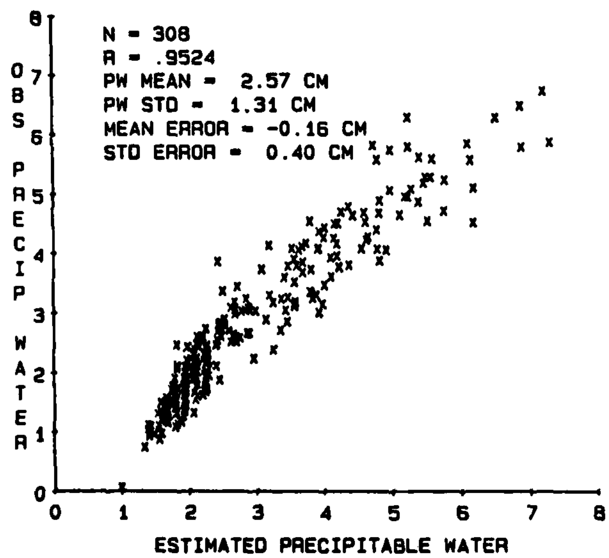

Figure 3. Precipitable water estimated by linear regression from transmittance ratio, versus observed precipitable water for independent radiosondes.

4. DISCUSSION

Thusfar the observational conditions have not been specified under which the surface contribution to the upwelling radiance changes, while the atmospheric contribution does not. Two situations immediately come to mind. The first has to do with the diurnal cycle of land surface heating. Figure 4 is a plot of 11 micrometer brightness temperature as observed by GOES W over an 11 hour period on 17 September 1983. The rate of change of brightness temperature during the local morning is in excess of 5 degrees per hour. Over a two hour period the ten degree brightness temperature change which discussed above can be seen. It is unlikely that the local absorber state would change dramatically over a two hour period, and if it did the surface would probably be obscured by clouds. Observation of diurnal temperature change is practical only from geosynchronous satellites.

The second situation is observing the earth cotemporally at adjacent contrasting surfaces. For example, measuring the brightness temperatures of a lake and the surrounding land. It might even be possible to use the heat island effect of a city with the contrasting cooler temperatures of the surrounding countryside. It is important however that the contrasting surface temperatures be geographically close, so that the assumption of invariant atmospheric temperature is met. This situation is viable for both geosynchronous and polar orbiting satellites.

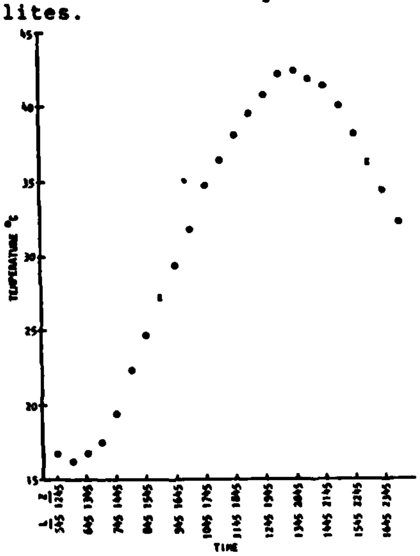

Figure 4. Eleven micrometer brightness temperature as a function of time as observed by GOES W on 17 September 1983. Average of 3x3 array of 7 km resolution elements, upper left corner at 36N, 120W, about 110 km NW of Bakersfield CA.

A technique has been presented which extends the split window technique to multiple observations in space or time. This extension allows for a simple derivation of transmittances of the split window, which can be related to precipitable water. Simulations of computed radiances with realistic instrument noise indicate that the technique yields an excellent estimate of the ratio of transmittances of the split window channels. Simple linear regression between the ratio and precipitable water also gives very good results. Testing of the technique with real AVHRR and VAS data is the logical next step in this research effort.

5. ACKNOWLEDGEMENTS:

The authors wish to express their appreciation to Mr. Mike Hill of NOAA/NESDIS for providing the radiative transfer code used in this study.

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